

28. FORAMINIFERA

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INTRODUCTION

Foraminifera were found in all sites drilled on Leg 22 (Figure 1). Neogene assemblages occur in the calcareous oozes on the Ninetyeast Ridge (Sites 214, 216, 217), in the redeposited carbonates in the Wharton Basin (Site 212), in the Bengal Fan section at Site 218, as reworked elements in the turbidites at Site 211, and as occasional specimens in deep-water, noncalcareous sediments. Paleogene assemblages were recovered from the sections on the Ninetyeast Ridge and from the sections on either side (Sites 213, 215). Occasional specimens were isolated from the Eocene chalk in the Wharton Basin, and specimens occur as reworked particles in the Miocene carbonate in the Wharton Basin and the Pliocene turbidites in the Bengal Fan. Upper Cretaceous assemblages occur on the Ninetyeast Ridge and at Sites 211 and 212.

This preliminary report concentrates mostly on the Eocene and below, partly because this part of the column has been sampled rather rarely in comparison with the Neogene during the Deep Sea Drilling Project and partly because foraminiferal data has proved pertinent to the basic geological problems which stimulated the drilling program. Also, valuable data on the composition of assemblages is provided in Chapters 9 and 30.

The main biostratigraphic results are expressed in Figures 2 and 3 in terms of those biostratigraphic events (local appearances and disappearances of species and morphotypes), or datums, judged to be important for correlation and age determination. This series of events from the oozes and chalks on the Ninetyeast Ridge is objective to the extent that they have been identified here, but they are shown in relation to the Cenozoic biostratigraphic system tabulated and quantified by Berggren (1972) against a geochronological scale and placed against a standard chronostratigraphic succession. By no means could all the defining events used in comprehensive biostratigraphic schemes (e.g., Bolli 1966, Blow 1969) be identified. The reasons are varying preservation in the deep sea, biogeographic and environmental constraints, and—relatively minor—sampling density and problems of identification. This procedure does not imply commitment to one particular biostratigraphy, nor to any special advantage in datums over zones, except convenience in avoiding a proliferation of zone nomenclature or zone combinations when events defining “standard” zones have not been identified. Nor, indeed, are the events listed here necessarily isochronous with the same events listed elsewhere, although this is disproved only when they are clearly out of predicted sequence.

OLIGOCENE-PLIOCENE

The three sections (Sites 214, 216, 217) on the Ninetyeast Ridge yielded fairly complete calcareous sequences. In these sections, specimens tend to be well preserved from the Pleistocene into the Pliocene, and the assemblages are of rich, low latitude aspect (keeled *Globorotalia*, *Pulleniatina*, *Sphaeroidinella*, *Globigerinoides*; *Globorotalia truncatulinoides* is present but not prominent). Preservation becomes poorer into the Miocene. The steps in the *Globigerinoides-Orbulina* bioseries are not recorded clearly. *Globorotalia fohsi* was found but the tests are always chalky and exfoliated. In the vicinity of the Oligocene/Miocene boundary, the *Globigerinoides* horizon is not clearly marked though early members of the genus were found, whereas, the important *Globorotalia kugleri* group is prominent because of the robust tests. Oligocene assemblages are dominated by robust, large forms of *Globoquadrina*, *Globigerina*, and *Globigerinita* and by small *Globigerina juvenilis*, *Chiloguembelina*, and *Pseudohastigerina*. The group of *Globigerina officinalis-ciperoensis-angulisuturalis* is represented only sporadically, and numerous small globigerinas are not characterized clearly. These broadly similar patterns have meant, at the level of preliminary study, that the history of test corrosion and solution has been rather similar at the three sites although they are successively deeper to the north and that there is little biogeographic contrast among the three sites above the level of statistical analysis. For example, the presence of later members of the *Globorotalia fohsi* lineage at Site 214 indicates that conditions were near “tropical” in the Middle Miocene.

Of the three sites, the biostratigraphy of Site 214 is summarized here in terms of appearances and disappearances of species considered to be important (Figure 2). Clustering in the Plio-Pleistocene in contrast to the Oligocene and Miocene reflects both preservation and general foraminiferal evolution. The Pliocene/Pleistocene boundary could be detected in the evolution of *Globorotalia truncatulinoides* from *G. tosaensis*. The evolution of *Sphaeroidinella dehiscens immatura* from *Sphaeroidinellopsis subdehiscens paenedehiscens* at the Miocene/Pliocene boundary was located less confidently. Events between these horizons are as expected. In the Miocene, zones down to N.13 were recognized and the boundaries located; below this level, less events defining the N and P zones could be located. The top range of *Globoquadrina dehiscens* s.s. seems to agree with data from southern Australia and New Zealand rather than extending into the Pliocene as shown by Blow (1969) and others.

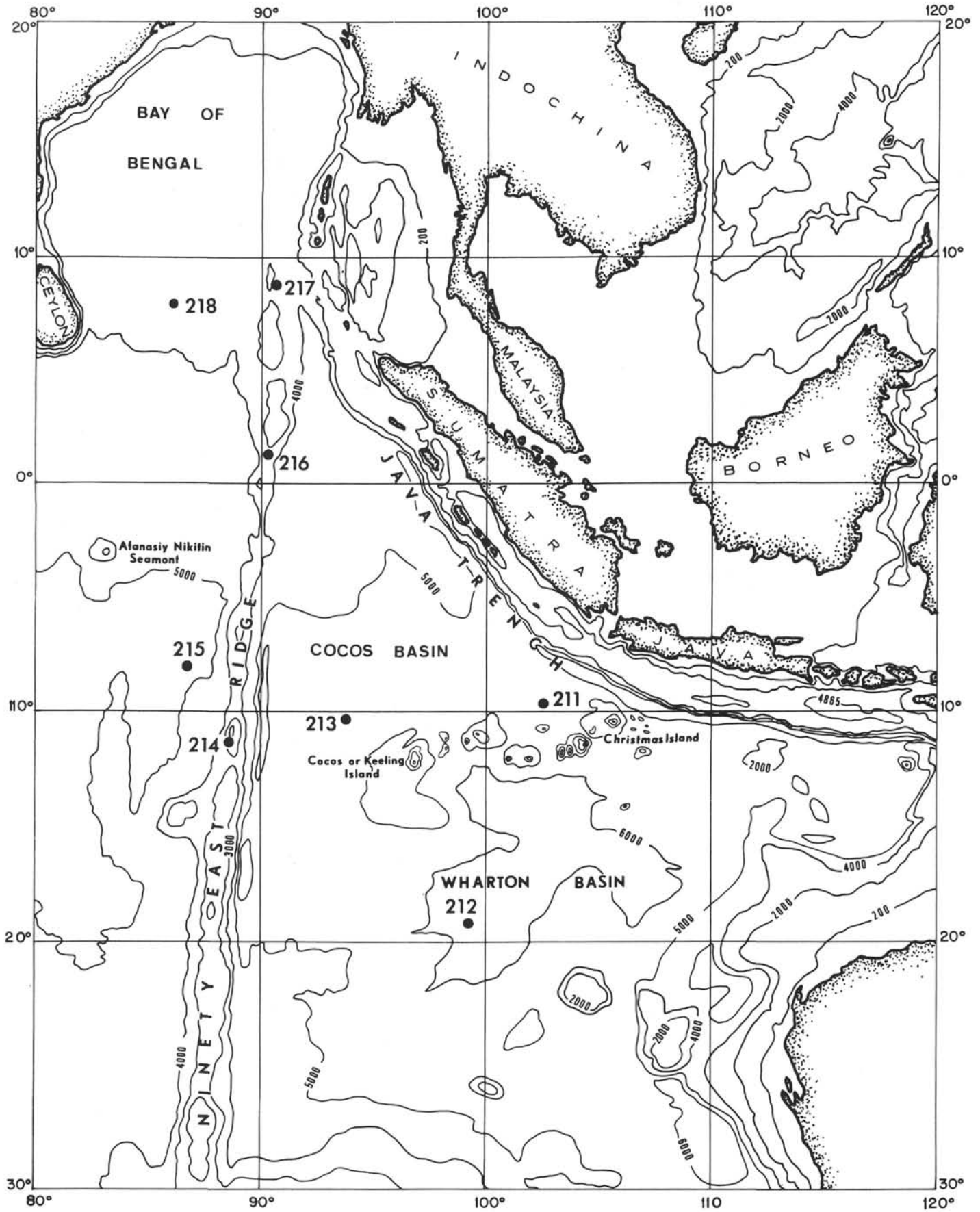


Figure 1. Drilling Sites, Leg 22.

Almost all Miocene events shown in Figure 4 refer to relatively robust forms. The range of *Globigerina binaiensis* above its ancestor *G. sellii* confirms its importance in the lower Miocene in this general region (Blow 1969). In the Oligocene, records of *Chiloguembelina*, "*Globorotalia*" *gemma*, *Subbotina angiporoides*, and *Pseudohastigerina* are important in providing links with extratropical sequences which are zoned on species not given prominence in tropical schemes.

The turbidites sampled at Site 211 contain rare foraminifera. Specimens of deeper-water benthonic provenance include *Hyalinea*, *Cibicidina*, *Florilus*, *Oridorsalis*, *Uvigerina*, *Bulimina*, and *Praeglobobulimina*. Forms from shallow water include *Elphidium* and *Pseudorotalia*, and the presence of the latter genus indicates that the sediment had a tropical origin. Planktonic pseudo-assemblages in Cores 7, 8, and 9 are small, but scattered specimens indicate ages for the source sediments of middle Miocene to Pliocene (*Globigerinoides bollii*), early to middle Miocene (*Globorotalia* [*Turborotalia*] *siakensis*), late Miocene to Pliocene (*Globigerinoides obliquus extremus*), and Pliocene or younger (*Globorotalia* [*Turborotalia*] *acostaensis pseudopima*, *Globorotalia tumida* s.s., *Sphaeroidinella dehiscens* s.s.). Long-ranging forms include *Globigerinoides quadrilobatus* s.l., *Globorotalia menardii* s.l., and *Globoquadrina altispira*. The maximum age of the lowest turbidites sampled (Core 9), accordingly, is considered to be Pliocene and perhaps, on the evidence of *G. (T.) acostaensis pseudopima*, mid-Pliocene (Zone N.20).

In the carbonate units at Site 212, foraminiferal evidence for redeposition includes both size-sorting and biostratigraphic mixing. Samples down to Core 9 yielded numerous small specimens and sporadic tests of normal size, including, among others, *Globigerinoides* spp., *Orbulina*, *Globigerina nepenthes*, *Globigerina* spp., *Globorotalia* (*Turborotalia*) spp., and *Globorotalia miozea/conoidea*. The presence of *Globorotalia conomiozea* indicates a maximum age of late Miocene while *G. (T.) siakensis* and *G. (T.) peripheroronda* indicate the mixing in of older material. Lower samples (down to Core 13) contain *Sphaeroidinellopsis*, *Globorotalia miozea/conoidea*, *Orbulina*, *Globigerina nepenthes*, and others (indicating a maximum age of middle Miocene) together with Oligocene species (*Globorotalia (T.) opima*, *Globigerina prasaepis*), and acarininids of middle Eocene age or older. It may be significant that *Globorotalia* is represented much more prominently by the *miozea-conoidea-conomiozea* group, which seems to flourish more in southern regions, than by *G. praemenardii*, and later members of this lineage, which are more typical at lower latitudes.

At Site 218, the foraminiferal content of samples varies markedly. Evidence for transport from shallow water includes rare and sporadic *Ammonia beccarii*, *Pseudorotalia* aff. *schroeteriana*, and *Elphidium* down to Core 27. Cores 1 to 8 contain evidence for Quaternary (*Globigerina calida* s.s., *Pulleniatina finalis*, *Globorotalia truncatulinoides*). Cores 8 and 9 contain Paleogene assemblages including *Planorotalites*, *Morozovella*, *Acarinina*, and *Chiloguembelina*. Cores 10 and 11 are Pliocene (*Globoquadrina altispira*, *Sphaeroidinella dehiscens* s.s., *Sphaeroidinellopsis*, *Globorotalia* [*Turborotalia*] *acostaensis pseudopima*).

Cores 12 to 27 are of Miocene age with a maximum age of middle Miocene (Zone N.13) for Core 26 based on the presence of *Sphaeroidinellopsis subdehiscens*.

PALEOCENE-EOCENE

Biostratigraphic events

The succession of observed biostratigraphic events, pieced together from Sites 214, 216 and 217 along the Ninetyeast Ridge, is shown in Figure 3. Figure 4 and Tables 1 through 5 show ranges of species.

Eocene/Oligocene Boundary

At Site 216, the highest occurrences of *Globigerinatheka* spp. and *Globorotalia cerroazulensis* are very close to the lowest record of *Globigerina tapuriensis*. Top of *Hantkenina* is distinctly lower but the foraminiferal assemblages are poor in this interval. At Site 216, these events could not be found in the interval between Core 17, Section 1 (middle Eocene) and Core 15. At Site 217, the Eocene/Oligocene boundary appears to be within Core 9. *Hantkenina* aff. *alabamensis* and *Globorotalia cerroazulensis* occur in Core 9, Section 5 but are absent in Core 9, Section 1, which contains *Pseudohastigerina micra*, *Chiloguembelina cubensis*, *Globigerina* aff. *tapuriensis*, and *G.* aff. *prasaepis*. In none of these sections is the material considered good enough to contribute positively to general foraminiferal biostratigraphy of the interval.

Upper/Middle Eocene Boundary

At Site 214, there is a well-marked offset between the last appearance of spinose acarininids (*Truncorotaloides collactea*) and the last appearance of *Planorotalites pseudoscutula* and *Morozovella crassata* just below. The lower horizon is taken as the upper/middle Eocene boundary. The down-section series of range tops (*Hantkenina*, "*Globorotalia*" *aculeata*, and *Subbotina* cf. *frontosa*) occurs in the same order as in southern "extratropical" sections (McGowran, in press), although the recognition of "*G.*" *aculeata* is continually doubtful at Site 214 due to poor preservation. Even so, this parallelism means that Site 214 is an important link between low-latitude sequences, with which it has more in common in this interval (consistent presence of *P. pseudoscutula* and keeled *Morozovella*, *Orbulinoides* together with excellent *M. coronata*, absence of *Acarinina primitiva*), and sequences at higher latitudes (similar in the slight extension upwards in range of acarininids, absence of *M. lehneri* above the *Orbulinoides* interval).

At Site 216, all of Core 17 is of uppermost middle Eocene age (above *Orbulinoides*, Zone P.13). Core 17, Sections 1 and 2, contain *Globorotalia pomeroli* and *G. cerroazulensis*, *Morozovella crassata*, *Planorotalites pseudoscutula*, *Truncorotaloides collactea/rohri*, and *Globigerinatheka* cf. *index*, among others. Rare and small *T. lehneri*, but not *Orbulinoides*, occurs in 17, CC. At Site 217, Core 10, Section 1 contains *M. crassata*, *M. lehneri*, *Globorotalia pessagnoensis* s.l., and the group of *Globigerinatheka euganea*. The same assemblage minus *M. lehneri* occurs in Core 10, Section 2. *M. aragonensis* appears in Core 10, Section 4, and *Orbulinoides* was not found. The evidence indicates, on the whole, that highest middle Eocene (Zone

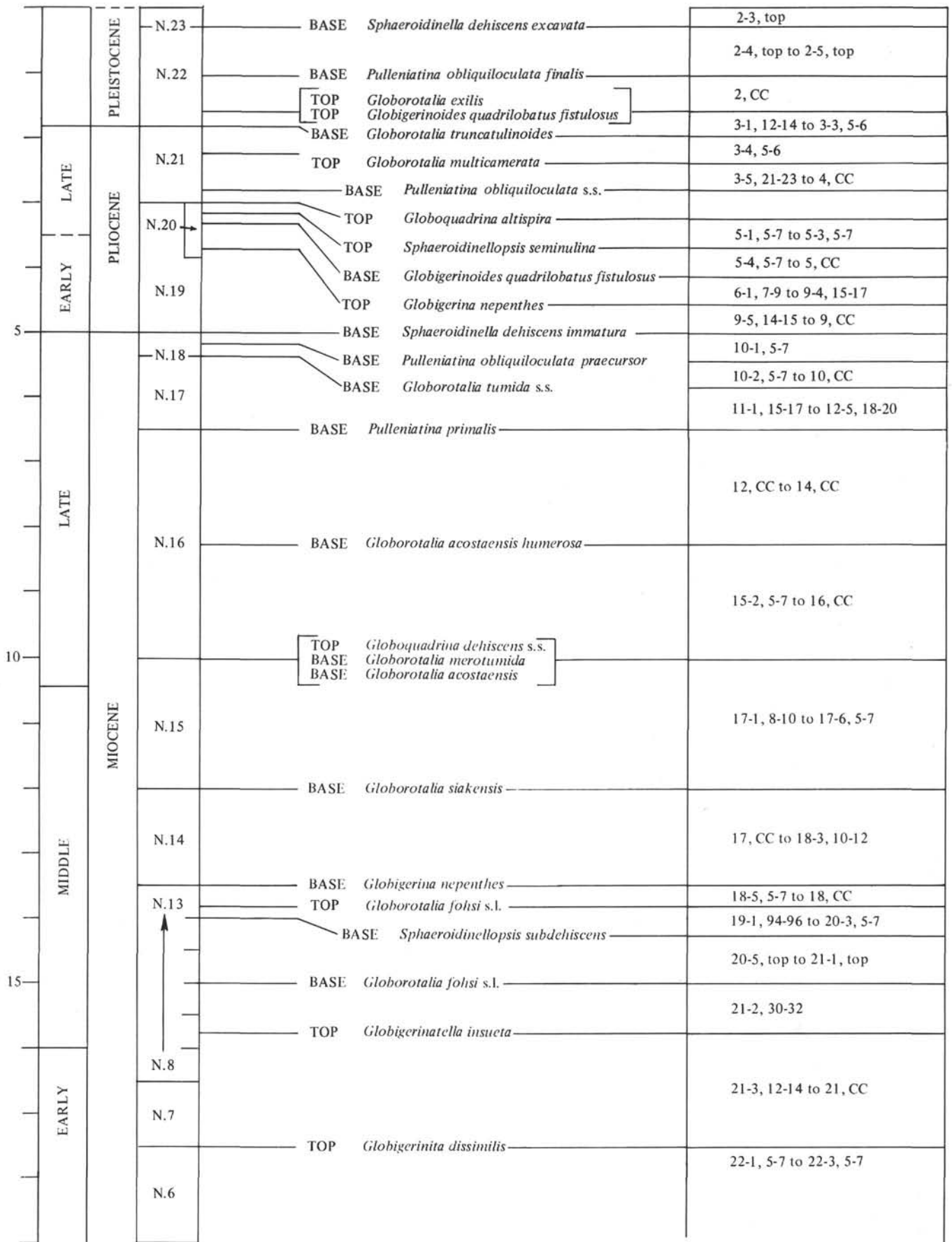
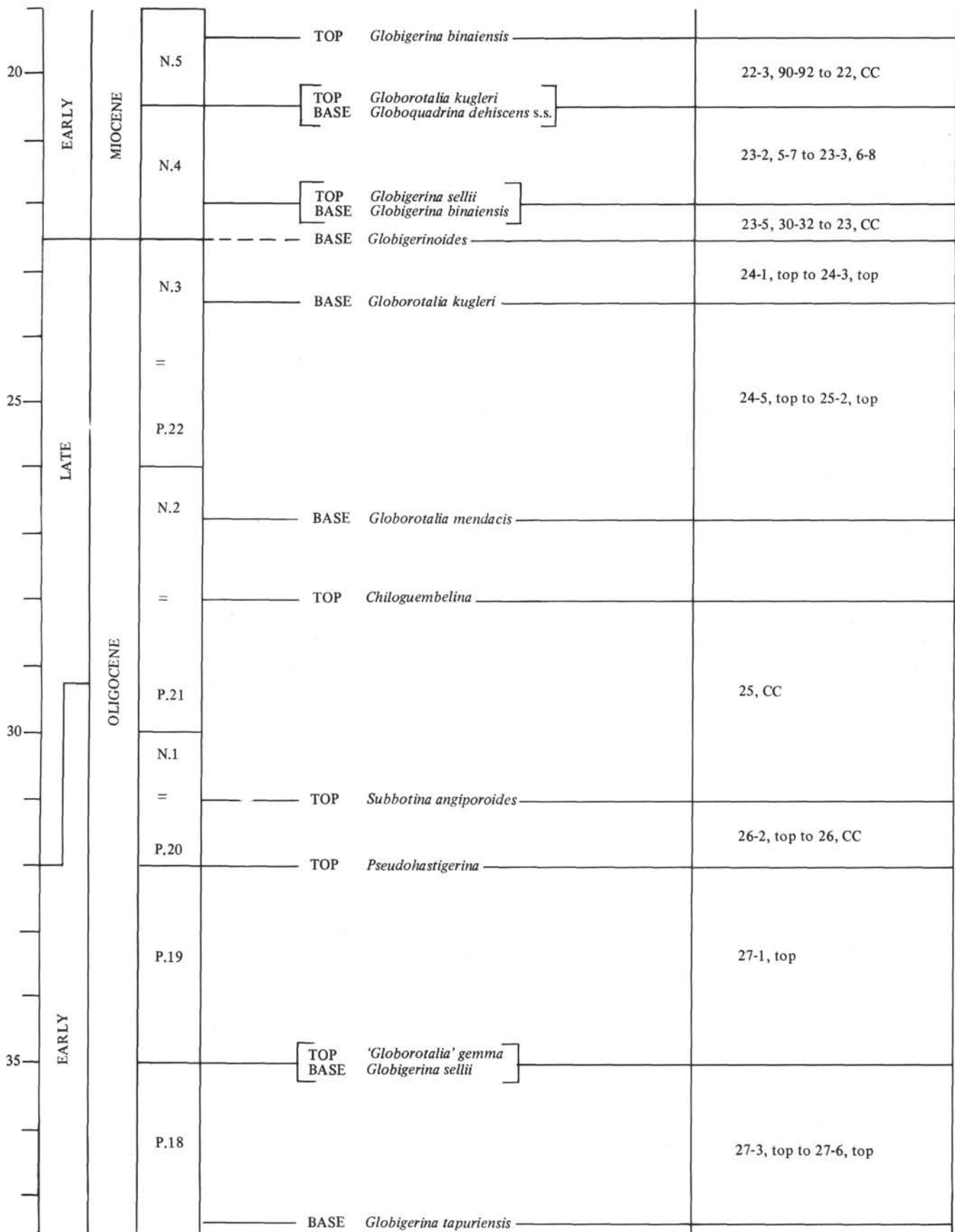


Figure 2. Biostratigraphic events, Oligocene to Pleistocene, Site 214, Ninetyeast Ridge. Numbering is standard: 3-1, 12-14 means Core 3, Section 1, 12-14 cm from top; CC is corecatcher. Where events are shown, "Top" is drawn as a horizon above the highest sample in which the species/morphotype is recorded, and "Base" is drawn below the lowest sample.



Where a Top and a Base are recorded in the same sample, the horizon shown refers to the Top. For example, Top *Globorotalia kugleri* and Base *Globoquadrina dehiscens* s.s. both refer to Sample 23-2, 5-7 cm, not 22, CC. Geochronological (m.y.B.P.), chronostratigraphic and biostratigraphic scale at left are taken from Berggren (1972).

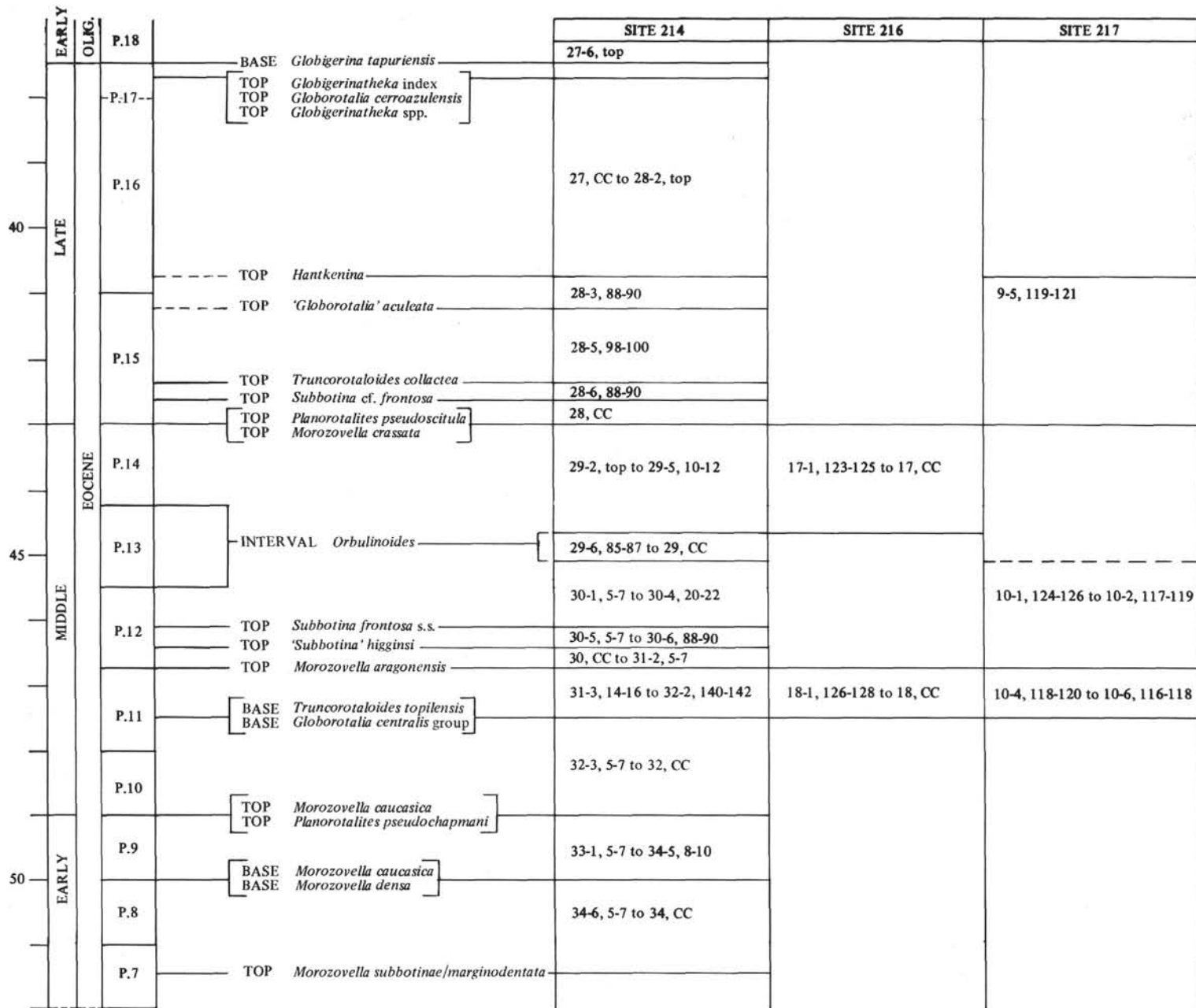


Figure 3. Biostratigraphic events, Maastrichtian to Eocene, Sites 214, 216, 217, Ninetyeast Ridge. For explanation, see Figure 2. Scale at left from Berggren (1972).

				SITE 214	SITE 216	SITE 217
EARLY EOCENE	P.6	BASE	<i>Morozovella aragonensis</i>	35-1, 50-52 to 36-2, 6-8		
		BASE	<i>Morozovella lensiformis</i>			
LATE PALEOCENE	P.5	TOP	<i>Morozovella velascoensis</i> s.l.		19-1, 139-141 to 19, CC	
		BASE	<i>Morozovella subbotinae/marginodentata</i>			
LATE PALEOCENE	P.4	TOP	<i>Planorotalites pseudomenardii</i>	36-3, 67-69 to 37-1, 98-100	20-3, 118-120 to 20, CC	12-1, 136-138 to 12, CC
		TOP	<i>Planorotalites chapmani</i>			
		TOP	<i>Morozovella angulata</i> group			
		TOP	<i>Morozovella acutispira</i>			
LATE PALEOCENE	P.3	BASE	<i>Planorotalites pseudomenardii</i>	37, CC to 41-3, 130-132		
		BASE	<i>Morozovella velascoensis</i> s.l.			
LATE PALEOCENE	P.2	BASE	<i>Morozovella conicotruncata</i>		22-1, 117-119 to 22, CC	13-1, 117-119 to 15, CC
		BASE	<i>Morozovella angulata</i>			
EARLY EOCENE	P.1	BASE	<i>Planorotalites ehrenbergi</i>		23-2, 8-10 to 23-2, 99-100	16-1, 18-20 to 16-3, 18-20
		TOP	<i>Globoconusa daubjergensis</i>			
EARLY EOCENE	P.1	BASE	' <i>Morozovella</i> ' <i>uncinata</i>			16-5, 34-36
		BASE	' <i>Subbotina</i> ' <i>inconstans</i>			
EARLY EOCENE	P.1	BASE	<i>Planorotalites compressa</i>			16-5, 58-60
		BASE	<i>Subbotina pseudobulloides</i>			
EARLY EOCENE	P.1	BASE	<i>Subbotina triloculinoides</i>			16-6, 118-120 to 16-6, 148-150
		TOP	<i>Globotruncana</i> etc.			
MST.		TOP	<i>Globotruncana</i> etc.			16, CC
		BASE	<i>Globotruncanella mayaroensis</i>			
					23-2, 110-111 to 24, CC	17-1, 80-82 to 23, CC
						24-1, 118-120

Figure 3. (Continued).

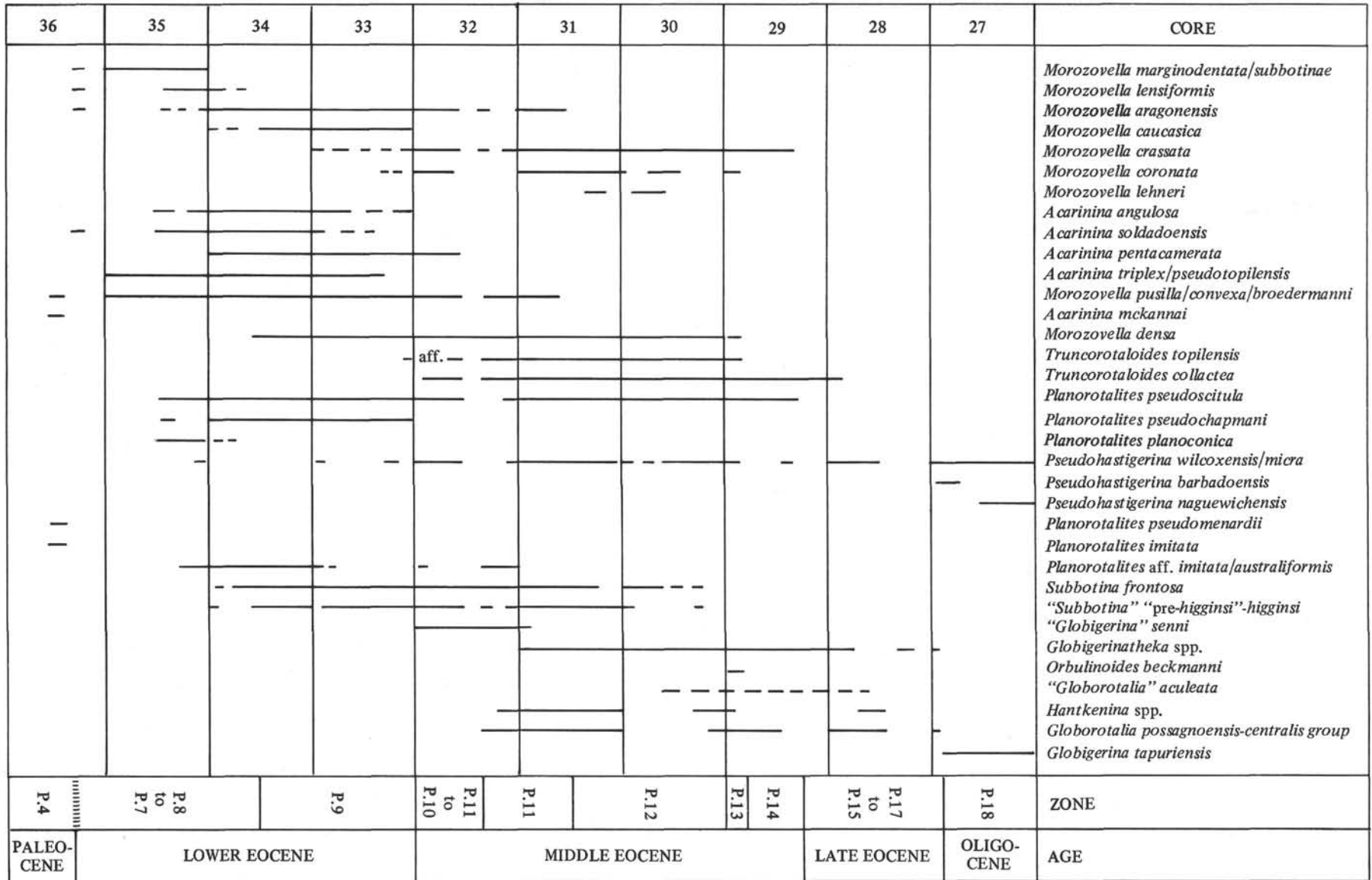


Figure 4. Ranges of selected species of planktonic foraminifera, late Paleocene to early Oligocene, Site 214.

TABLE 1
Early Middle Eocene Biostratigraphy at Site 214

Core	Section	Interval (cm)	Abundance	Preservation	<i>Morozovella crassata</i>	<i>Morozovella coronata</i>	<i>Morozovella lehneri</i>	<i>Morozovella aragonensis</i>	<i>Morozovella broedermanni</i>	<i>Morozovella densa</i>	<i>Truncorotaloides topilensis</i>	" <i>Truncorotaloides</i> " <i>collactea/rohri</i>	<i>Acarinina primitiva</i>	" <i>Globigerinita</i> " <i>echinatus</i>	<i>Pseudohastigerina wilcoxensis</i>	<i>Planorotalites pseudoscutula</i>	<i>Planorotalites australiformis</i>	<i>Hantkenina aragonensis/dumblei</i>	<i>Acarinina rotundimarginata</i>	" <i>Globigerina</i> " <i>pseudovenezuelana</i> , etc.	<i>Turborotalia wilsoni/pseudomayeri/nana</i>	<i>Subbotina yeguensis</i>	" <i>Subbotina</i> " <i>higginsi</i>	<i>Subbotina frontosa</i>	" <i>Globorotalia</i> " <i>possagnoensis</i>	<i>Subbotina linaperta/angiporooides</i>	" <i>Globigerina</i> " <i>senii</i>	<i>Globigerinatheka</i> sp.	<i>Globigerinatheka index/tropicalis</i>	<i>Globigerinatheka curryi/euganea</i>	<i>Chiloguembelina</i> spp.	Correlation	Age		
31	1	5-7	C	M	+	+				+	+	+			+	+	+	+	+	+	+	+	+												
	2	5-7	C	M	+	+	+		?	+	+	+			+	+	+	+	+	+	+	+	+	+											Zone P.12
32	3	14-16	C	M	+	+		+			+	+				+	+			+	+	+	+	+	+	+									
	4	30-32	C	M	+	+		+	+	+	+	+				+	+			+	+	+	+	+	+	+									
	5	12-14	C	F	+			+	+	+	+	+				+	+			+	+	+	+	+	+	+									
	6	5-7	A	F	+	+		+	+	+	+	+				+	+			+	+	+	+	+	+	+									
	CC		A	F	+	+	?	+	+	+	+	+				+	+			+	+	+	+	+	+	+									
	1	Top	A	F	+				+	+	+	+	?			+	+			+	+	+	+	+	+	+	+	+							
	1	132-134	A	F					+	+	+	+	+	?			+			+	+	+	+	+	+										
	2	8-10	A	F	+				+	+	+	+	+	?			+			+	+	+	+	+	+	+									
	2	20-22	A	F	+				+	+	+	+	+	+	+	+	+			+	+	+	+	+	+	+	+								
	2	90-92	A	F	+				+	+	+	+	+	+	+	+	+			+	+	+	+	+	+	+	+								
2	140-142	A	F					+	+	+	+	+	+	+	+	+			+	+	+	+	+	+	+	+									
33	3	5-7	VR	F						+										+	+	+													
	3	35-37	A	F					+	+	+	aff	+	+		+	+			+	+	+	+												
	3	105-107	A	F	+				+	+	+	aff	+	+	+	+	+			+	+	+	aff	+											
	4	5-7	A	F	+	+			+	+	+	aff	+		+	+	+			+	+	+	aff	+											
	5	5-7	A	F	+	+			+	+	+	aff	+		+	+	+			+	+	+	aff	+											
	6	3-5	A	F	+	+			+	+	+	aff	+			+	+			+	+	+	aff	+											
	CC		A	F	+	+			+	+	+	aff	+			+	+			+	+	+	aff	+											
33																																			

P.14) is present at Site 216. This is based on the assumption that *M. lehneri* occupies more of its full tropical range (*M. lehneri* extinction datum at top of Zone P.14; Berggren, 1972) than at Site 214 (Figure 4).

The possible significance of middle Eocene planktonic foraminiferal biostratigraphy on the Ninetyeast Ridge is discussed below.

Occasional small specimens of *Chiloguembelina* and globigerinids were found in the tough, fine-grained chalk at Site 212. It is likely that most of the zeolitic clay at Site 213, between the well dated middle Miocene siliceous and Lower Eocene calcareous units, is Eocene in age. Core 13, CC contains agglutinated benthonics and fish remains together with rare *Morozovella* aff. *spinulosa*, *Turborotalia* aff. *pseudomayeri*, *Acarinina* aff. *primitiva*, and a fragment of either *Globigerinatheka* or "*Subbotina*" *higginsi*. Core 11, CC contains fish remains and rare *Morozovella densa*,

Acarinina aff. *primitiva*, and *Turborotalia* sp. Both assemblages are of middle Eocene age.

Middle/Lower Eocene Boundary

The top occurrence of the distinctive species *Morozovella caucasica* is well marked although it occurs between Cores 32 and 33. The lowest *Hantkenina* were found in Core 32, Section 2. They are primitive forms but, perhaps, are a little closer to *H. dumblei* than *H. aragonensis*. Thus, the *Hantkenina* datum at the lower/middle Eocene boundary (Berggren, 1972) is not considered reliable here, probably for climatic reasons. The range recorded here of *Planorotalites pseudochapmani* is consistent with the original record, (Gohrbandt, 1967) and its disappearance together with *M. caucasica* suggests that the species will become more important than the lack of records to date would indicate.

TABLE 2
Paleocene-Eocene Transition at Site 213

Core	Section	Interval (cm)	Abundance	Preservation	fish teeth, etc.	<i>Glomospira</i> spp.	" <i>Reophax</i> " sp.	<i>Cibicides/anomalinoideis</i>	<i>Heterolepa</i> spp.	<i>Gaudryina</i> sp.	<i>Nuttallides</i> sp.	<i>Aragonia</i> sp.	thin-walled nodosariids	<i>Acarinina</i> aff. <i>primitiva</i>	<i>Acarinina soldadoensis</i>	<i>Morozovella lensiformis</i>	<i>Acarinina angulosa</i>	<i>Morozovella aragonensis</i>	<i>Acarinina pentacamerata</i>	<i>Subbotina</i> spp.	<i>Morozovella formosa</i> s.s.	<i>Acarinina pseudotopilensis</i>	<i>Morozovella subbotinae/marginodentata</i>	<i>Morozovella aequa</i>	<i>Planorotalites pseudoscitula</i>	<i>Morozovella velascoensis</i> s.l.	<i>Morozovella velascoensis</i> s.s.	Correlation	Age			
14	1	90-92	R	M	+	+	+																									
	2	90-92	R	M	+	+	+																									
	3	90-92	R	M										+																		
	4	140-142	R	M	+	+	+																									
	5	110-112	R	M	+	+	+	+	+	+	+	+																				
	6	46-48	R	M	+	+	+	+	+	+	+	+	+	+																		
14 15	6	90-92	R	M	+				+				+	+	+	+																
	6	145-147	C	P	+					+			+	+	+	+	+	?														
	CC		A	M		+	+	+		+			+	+	+	+	+	?	+	+												
	1	117-119	C	P	+	+	+	+		+	+		+	+	+	+	+															
	1	146-148	R	P	+	+	+	+	+	+			+	+	+	+	+															
	2	142-144	F	M	+	+	+	+		+			+	+	+	+	+															
	3	80-82	A	M											+	+	+	+	+			+	+	+								
	3	130-132	A	G											+	+	+	+	+			+	+	+								
	4	32-34	C	M											+	+	+	+	?			+	+	+								
	4	146-148	C	M											+	+	+	+				+	+									
15	5	5-7	A	G										+	+	?	+				+	?		+	+	+						
	5	112-114	A	G																												
	6	40-42	A	E																												
	CC		A	E																												
16	1	92-94	A	E									+										+	+	+	+	+	+				
	1	142-146	A	+																												
	2	20-22	A	E																												
	3	30-32	A	E																												
	3	146-148	A	E																												
	4	20-22	A	E																												
	4	80-82	A	E																												
	4	130-134	A	E																												
CC		A	E																													
																As above, plus contaminants from Core 15																
																										Zone P.7	Lower Eocene					
																										Zone P.6b						
																										Zone P.6a	Upper Paleocene					

Lower Eocene and Paleocene/Eocene Boundary

Lower Eocene assemblages are typical in that they include the group of *Morozovella subbotinae/marginodentata*, *M. lensiformis*, and *M. aragonensis* and acarininids of the *soldadoensis/angulosa*, *triplex/pseudotopilensis*, and *pentacamerata* morphotypes. The stratigraphic nonoverlap of *M. lensiformis* and *M. densa* is consistent (see Berggren, 1971) but is recorded here rather tentatively. With reference to biostratigraphic events at or close to the Paleocene/Eocene boundary, the top range of *Morozovella velascoensis* s.l. is clear cut compared with the base range of

Pseudohastigerina which is not and problems with the latter datum and *Planorotalites-Pseudohastigerina* relationships (McGowran, 1970) have not been clarified here except that the disappearance of typical *P. chapmani* below top *P. pseudomenardii* is confirmed.

At Site 214, *Morozovella aragonensis*, *M. lensiformis*, and acarininids of lower Eocene aspect continue downwards through the facies change between the calcareous ooze of Core 34 and the glauconite-carbonate of Core 35, and the lowest occurrence of *M. aragonensis*, within strongly glauconitic sediments, is in Core 36, Section 2.

TABLE 4
Paleocene and Cretaceous/Tertiary Boundary at Site 216

Core	Section	Interval (cm)	Abundance	Preservation												Correlation	Age																			
19	1 CC	139-141	F	VP	+	+	+	+	+	+	+	+	+	+	+	Zone P.6a	Late Paleocene																			
			P	+	+	+	+	+	+	+	+	+	+	+	+																					
	20	1 2	118-120 118-120	C	P	?	+						+	?	+	+		+	Zone P.5																	
				C	P	+	+								+	?		+		+	?															
	21	3 CC	118-120	A	F	+	+							+	?	+		+	Zone P.4 (upper)																	
				A	F	?	+									+		+		+	+															
		1 2	130-132 15-17	A	F		+						?	+	+	+		+		+	+	+														
				A	F		+								+	+		+		+	+	+	+													
	22	1 2	117-119 130-132	C	F		+							+	+	+		+	+	Zone P.4 (lower)																
				C	F		+								+	+		+	+		+	+														
	23	1 2 2	Top 8-10 99-100	C	F													?	+	+	+	+	?	+	?	+	?									
				C	F																					+	+	+	+	+	+	+	+			
C				P																						+	+	+	+	+	+	+				
23	2 2 3 3 CC	110-111 120-123 17-19 121-123	R	P																											<i>Globotruncanella mayaroensis</i> Zone	Late Maastrichtian				
			R	P																																
			R	P																																
			C	P																																
	3 CC		C	P																																
			C	P																																

TABLE 5
Paleocene and Cretaceous/Tertiary Boundary at Site 217

Core	Section	Interval (cm)	Abundance	Preservation	Morozovella velascoensis s.s.	Morozovella velascoensis s.l.	Morozovella "pre-aequa"	Morozovella pusilla/convexa	Acarina sp.	Acarina mckannai	Planorotalites pseudomenardi	Planorotalites imitata	Planorotalites chapmani	Morozovella acutispira	Morozovella angulata/conico truncata	Subbotina variata	Planorotalites ehrenbergi	Subbotina pseudobulloides	Morozovella uncinata	Planorotalites compressa	Subbotina inconstans	Subbotina praecursoria	Subbotina triloculinoidea	Globocornusa daubjergensis	Eoglobigerina eobulloides	Chilogaembelina midwayensis s.s.	Chilogaembelina morsei	Chilogaembelina subtriangularis	Globigerinelloides sp.	Rugoglobigerina spp.	Globotruncana spp.	Hedbergella sp.	Globotruncanella mayaroensis	Globotruncanella intermedia	Globotruncana stuarti s.s.	Globotruncana stuartiformis	Globotruncana conica	Globotruncana contusa	Globotruncana arca	Globotruncana aff. elevata	Globotruncana aegyptiaca	Globotruncanella citae	Rugoglobigerina aff. scotti	Pseudotextularia elegans/varians etc.	Gublerina cuvillieri	Bolivinoidea draco s.s.	Correlation	Age						
12	1	136-138	A	F	+	+	+	+	+	?	+	+																																										
	CC		A	F	+	+	+	+	+																																													
13	1	60-62	A	F	+	+	+	+			+	+	+	?																																								
14	1	117-119	A	F	+	+		+	+	+	+	+	+	+																																								
	CC		A	F	+	+		+		+	+	+	+	+																																								
	1	18-20	C	F	+	+		+						?	+	+	+																																					
	3	18-20	C	F	+	+		+			+	+	+	?	+	+	+																																					
	5	18-20	C	F	+	+		+			+	+	+	?	+	+	+																																					
15	1	122-124	A	F	+	+					+	+	+	?	+	+	+																																					
	2	116-118	C	F				+			+	+	+		+	+	+																																					
	CC		C	P				+			+	+	+		+	+	+																																					
16	1	18-20	A	F													+	+	+			+	+	+	+	+																												
	2	18-20	A	F														+	+	+			+	+	+	+	+																											
	3	18-20	C	F										+				+	+	+			+	+	+	+	+																											
	5	34-36	C	F														+		+					+	+	+																											
		5	58-60	C	F														+					+				+	+	+																								
	6	118-120	C	P																							+	+	+																									
	6	148-150	C	P																							+	+	+	+	+																							
	CC		C	F																							+	+	+	+	+																							
17	1	80-82	C	F																																																		
	CC		R	P																								+	+		+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+		

(Clustering of initial appearances in Core 35, shown in Figure 4, is a facies artifact.) Core 36, Sections 3 and 4 contain *Planorotalites pseudomenardii*, *P. imitata*, *Morozovella laevigata/convexa*, and *Acarinina mckannai*. The change represents a break between Zone P.7 (lower Eocene) and Zone P.4 (Paleocene) and indicates a hiatus (within sampling limits of one core section) of 4 m.y. or more. At Site 216, Core 18 is middle Eocene; Core 19, Section 1 and Core 19, CC contain *Morozovella velascoensis* (*occlusa* morphotype), *M. aequa*, *M. subbotinae/marginodentata*, *Planorotalites pseudoscutula*, *P. planoconica*, *Acarinina coalingensis/soldadoensis/pseudotopilensis*, and (19-1 only) *Subbotina patagonica* and a mixture of, or transition between, *Planorotalites* aff. *imitata* or *?simplex* and *Pseudohastigerina wilcoxensis* of the *pseudoiota* type. Thus, Core 19 is placed in Zone P.6a, and the lower Eocene was not sampled. At Site 217, Core 10 is of middle Eocene age; Core 11 was empty; Core 12, Section 1 contains an assemblage with *Planorotalites pseudomenardii*, and this is in Zone P.4.

The Paleocene/Eocene boundary is recorded better on either side of the Ninetyeast Ridge than in sites on the crest. At Site 213 (Table 2), Core 14 records a change downhole from brown clay with poor fossil material to dateable samples at the base, and Cores 15 and 16 are progressively better. The chronostratigraphic boundary is placed between Cores 15 and 16; the occurrence through Core 16 of *Morozovella velascoensis* s.s. and variants together with the *M. subbotinae/marginodentata/gracilis* group identifies Zone P.6a. At Site 215 (Table 3), this zonation is obscured by poor assemblages, and there is no overlap in the ranges of the two groups of *Morozovella*. Thus, the greater part of Core 12 is not dated clearly either as Paleocene or as Eocene when the boundary is placed at the Zone P.6a/P.6b contact.

Paleocene

The Paleocene sections on and adjacent to the Ninetyeast Ridge are typical of the Paleocene in general, in that Zone P.4 in the Upper Paleocene is the best developed part. The Danian was identified at Sites 216 and 217 (see below).

At Site 214, the upper boundary of Zone P.4 is a disconformity below Zone P.7. At Site 216, the Zone P.5/P.4 boundary within Core 20 is placed at a facies change, the assemblages being poorer in Zone P.5. At Site 217, Core 11 was empty and Core 12 is in Zone P.4. At Site 215, the sequence is obscured by fluctuations in the abundance of planktonics. However, several points concerning Zone P.4 assemblages might be made. The gap between the *Morozovella angulata/conicotruncata* group (lower Zone P.4) and *M. aequa* (Zone P.5) is occupied by a form, listed here as *M. "Pre-aequa"*, which occurs also in "extratropical" western Australia and elsewhere. "*Globorotalia*" *apanthesma* and other names may refer to it. Acarininids in Zone P.4 are dominated by *A. mckannai*, as expected. This species disappears near the boundary, and the *A. esnaensis* group becomes more prominent in Zone P.5. The disappearance of typical *Planorotalites chapmani* below *P. pseudomenardii* is confirmed. *Morozovella acutispira*, prominent in "extratropical" western Australian

and Northern Hemisphere assemblages, is restricted to the lower part of Zone P.4. Thus, a subdivision of Zone P.4 is suggested here (Tables 3, 4, 5).

There is no lower boundary to Zone P.4 other than in sampling gaps or facies changes. Zone P.3 is poorly represented at Sites 214 and 215 and was recognized in one sample at Site 216. Zone P.2 was not recognized, and Zone P.1 is discussed separately below.

Igneous Rock/Sediment Contacts in the Paleocene

At Site 213, rich planktonic assemblages continue down to Core 16, CC. The lowest fossiliferous material recovered was removed ultrasonically from the surface of the top four pieces of basalt in Sample 17-1, 0-12 cm. This material consists of small specimens in two distinct preservations, one of which might be downhole contamination. Relatively fresh specimens include *Morozovella velascoensis* (*occlusa* morphotype), *M. aff. aequa*, *M. cf. subbotinae* or *M. cf. acutispira*, *M. pusilla/convexa*, and *Planorotalites* aff. *imitata*. Specimens stained brown include *M. pusilla/convexa*, *P. aff. imitata*, *Subbotina* sp., and both calcareous and agglutinated benthonics. The evidence indicates a maximum age of Zone P.4, i.e., 58 m.y. (Figure 2).

At Site 215, assemblages with *Planorotalites pseudomenardii*, i.e., Zone P.4, continue down to Core 17, Section 1 in a sample taken immediately above the hardened sediment over the igneous unit. The assemblage is not as good as in Core 16, CC, but a firm maximum age of 58 m.y. can be given. Calcareous sediment between basalts in Core 17, CC yielded a poor assemblage because of lithification, not solution effects. However, the presence of *Morozovella angulata* s.l., *M. aff. pusilla*, and *Planorotalites ehrenbergi* indicates Zone P.3 and a maximum age of 60 m.y.

The planktonic assemblages in the lowest marine sediments at Site 214 are relevant here in that they provide some support to the palyno-biostratigraphy (Chapter 24). The *Gambierina edwardsii* Zone relies heavily for its age determination on a marine incursion in southern Australia. A poor planktonic foraminiferal assemblage in this incursion (Pebble Point Formation) has been correlated tentatively with Zone P.3 solely on the basis of *Planorotalites haunsbergensis* (McGowran, 1965, 1970). The downward extent of the *G. edwardsii* Zone has not been located chronostratigraphically. At Site 214, Zone P.4 extends from Core 36, Section 2 (with *Planorotalites pseudomenardii*) down to Core 38, CC with a few poor specimens of *Planorotalites chapmani* in Cores 37 and 38. In Core 39, only subbotinids and primitive acarininids have been found. Planktonics in Core 40, Section 1 and Core 41, Section 3 are of extratropical aspect and not directly comparable with good index species in tropical sections. However, the presence of cf. *Globoconusa* of the *daubjergensis/kozlowski* lineage, primitive acarininids, and *Morozovella* aff. *angulata* suggest indirectly, with reference to northern extratropical assemblages (e.g., Olsson, 1969, Moorkens, 1972), Zone P.3 and a maximum age of 59 to 60 m.y.

Middle Eocene Biostratigraphy, Ninetyeast Ridge

The distribution of morphotypes in Cores 31 and 32 at Site 214 (Table 1) includes several details which show that

the section is not "fully tropical." *Morozovella caucasica* is well developed in regions such as Malagasy and New Zealand, and *Morozovella aragonensis* occurs fairly consistently in the section until its disappearance at about the right place below the *Orbulinoides* interval. The respective disappearances, therefore, can be taken as bracketing the Zone P.10-P.11 interval in the expectation that the boundaries thus defined have chronostratigraphic significance. Within this interval, however, the lowest appearance of "*Globorotalia*" *possagnoensis* and *Truncorotaloides topilensis* are not consistent with lowest *Hantkenina*; the latter genus seemingly appearing here in Zone P.11 instead of Zone P.10.

In Core 32, Section 3, the sample at 5-7 cm contrasts strongly with those on either side in that the residue is very sparse and consists only of robust forms: "*Globigerina*" *senni* (the dominant form), *Morozovella densa*, *Subbotina*, and "*Globigerina*." Keeled *Morozovella* is absent from this sample and mostly absent in its vicinity. At or near this level, "*G.*" *possagnoensis*, *Globigerinatheka*, *Chiloguembelina*, and *Hantkenina* come in, as does *T. topilensis* (this species is fully developed in its form, keel, and ornament but usually lacks supplementary apertures). Also, however, there is a prominent but shortlived development of the southern extratropical species *Planorotalites australiformis*, and the typically extratropical *Acarinina primitiva* was distinguished clearly from other acarininids only in this part of the section. In Core 32, acarininids become more common upwards, and the development of calcite crusts on tests becomes more prominent.

It seems likely that these points reflect a brief incursion into the area of colder water bringing with it two well-known species from higher latitudes, delaying the entry of *Hantkenina*, and disrupting the range of keeled *Morozovella*.

Chert was first encountered at Site 216 in Core 18. The associated assemblage is poorly preserved but includes *M. aragonensis*, *M. coronata/crassata*, *M. densa*, *T. topilensis*, *A. primitiva*, *Globigerinatheka*, *S. frontosa*, *P. pseudo-scitula*, and others. This is zone P.11, close to, but slightly younger than the interval of pronounced change at Site 214.

Chert was not recovered from the middle Eocene at Site 217, but it may be significant that Core 11 was empty. Core 10, Section 4 to Core 10, CC has a poorly preserved assemblage with *M. aragonensis*, *M. crassata*, "*G.*" *possagnoensis*, and *Globigerinatheka*, also indicating Zone P.12.

Lower Tertiary Biofacies, Ninetyeast Ridge

Shallow Water Facies, Site 214

Cores 40 and 41, at the base of the marine section, contain diverse foraminiferal assemblages in which benthonics are much more common than planktonics. These cores are distinguished as a unit (Table 6) by diversity and relatively good preservation. The assemblages are very similar to an "extratropical," shallow-water assemblage in the Paleocene Pebble Point Formation in southern Australia (McGowran, 1965) in being dominated by *Karrerina pseudoconvexa*, *Cibicides umbonifer*, and related forms,

Gyroidinoides octocamerata and others, *Cibicidina ekbloimi*, and *Alabamina westraliensis*. Perhaps the most striking similarity—and contrast with assemblages of similar age and environment in the Northern Hemisphere—is the presence in some numbers of *Baggatella* aff. *coloradoensis* and *Epistominella* cf. *vitrea*. Further points of resemblance are the presence of *Ceratobulimina* (close to, but not the same as *C. westraliensis* and *C. jutlandica*) and uvigerinids occupying the place of *Kolesnikovella angusta*, and, finally, the virtual absence of miliolids and agglutinated forms. The geological and stratigraphical setting of the southern Australian assemblage is far stronger evidence for a shallow-water environment than an actualistic analysis of the components would be, and a simple comparison with this near-coeval assemblage leads to the same conclusion here. The lack of miliolids and agglutinated tests and the presence of various invertebrate remains probably means water of normal salinity. The lower part of the second unit distinguished (Table 6) is essentially similar in its foraminiferal content except that numbers are less, preservation is poorer, and several of the forms prominent below have not been found. Below the interpreted hiatus in Core 36, planktonic numbers are much higher than below. The dominance of *Acarinina* and *Subbotina* over other genera probably indicates extratropical conditions as well as, perhaps, shallow water (Olsson 1969) (it is noteworthy that *Subbotina* is highly dominant at the base of the section at Site 215, in deeper water). Foraminiferal residues from Core 36, Section 2 to Core 35 are different in that the glauconite has changed color from olive green to partly rust colored and benthonic foraminifera are less common, although *Cibicides*, which was attached to plants (indicating the photic zone), is present, as are fecal pellets. The change in the planktonic assemblages, with keeled *Morozovella* and *Planorotalites* becoming prominent, may indicate warmer water as well as a younger age. In Table 6, the word "shelf" is, of course, used loosely and as if Site 214 were drilled on a continental margin.

Deep Water Facies, Site 215

The foraminiferal assemblages here are very different from those of similar age at Site 214, and there are marked differences in content and preservation. Thus, in Cores 10 and 11 (Table 3), planktonics are common to abundant and their preservation is good while benthonics are few and small and fish remains and clay are rare. In Core 9 and much of the Paleocene, on the other hand, planktonics are rare to absent and corroded or fragmented, while benthonics are relatively common though variable in preservation and there are substantial clay and fish remains. Both benthonics and good planktonic assemblages occur in the lowest samples above the igneous unit. The benthonics include both agglutinated and calcareous-lamellar forms, and the latter tend to be robust and strongly calcified. The record, summarized in Table 3, would seem to indicate concentration of benthonics below the lysocline during the Paleocene (after initial deposition of calcareous ooze) followed by a calcareous sequence in the lower Eocene. But the Paleocene section seems unduly thick for the 2 m.y. interval occupied by Zone P.4. The benthonics, mostly, are known from the carbonate shelf facies in western Australia,

TABLE 6
Facies Changes in Early Tertiary, Site 214

Core Section	Summary of Biofacies (Mostly Foraminiferal)	Interpretation
34	Abundant planktonic foraminifera. Rare benthonic foraminifera.	Oceanic
35 to 36-2	Planktonic foraminifera abundant at top, decreasing downwards; <i>Morozovella</i> and <i>Planorotalites</i> common to abundant. Benthonic foraminifera includes <i>Cibicides</i> attached to plant stems. Sediment is glauconitic, with echinoid spines, fecal pellets, shelly material.	Outer Shelf Deepening upwards, warmer than below
36-3 to 39	Planktonic foraminifera decrease downwards; <i>Acarinina</i> and <i>Subbotina</i> dominant, <i>Morozovella</i> and <i>Planorotalites</i> subordinate to absent. Benthonic foraminifera increase downwards in numbers but variable in numbers and dominances; preservation poor. Main types: <i>Cibicides</i> , <i>Karreria</i> , <i>Alabama</i> , <i>Gyroidinoides</i> , <i>Cibicidina</i> , univerrinids. Agglutinated and porcellanous forms rare to absent. Sponge spicules, echinoidal and molluscan fragments, ostracods.	Hiatus: absence of Zones P.5 and P.6 Inner Shelf Deepening upwards "extratropical"
40 to 41	Planktonic foraminifera present but subordinate to benthonics. Benthonics better preserved than above; assemblages dominated by <i>Karreria</i> , <i>Alabama</i> , <i>Gyroidinoides</i> , <i>Cibicides</i> , <i>Cibicidina</i> , <i>Baggatella</i> , <i>Epistominella</i> , <i>Ceratobulimina</i> , uvigerinids, lagenids; no porcellanous or agglutinated forms. Sponge spicules, echinoidal and molluscan fragments, ostracods.	Inner Shelf Very shallow, salinity close to normal "extratropical"

but species of *Nuttallinella*, *Gyroidinoides*, *Anomalinoidea*, *Cibicides*, *Oridorsalis*, and other genera are more similar to, and in some cases identical with, the Upper Cretaceous forms on the shelf; few of the latter extend into the Paleocene. In particular, *Nuttallinella* and an undescribed gavelinellid (= "*Porosotalia* sp." of Todd, 1970) are common Cretaceous forms in western Australia, and both occur in the Cretaceous at Site 217. In deeper water benthonic assemblages, however, there is considerable continuity across the Cretaceous/Tertiary boundary, and it is quite likely that *Nuttallinella* and others survived at depth for some time after they were displaced from their niches on the shelf. Alternatively—and helping to explain the thickness of Zone P.4—older material could have slumped to the site, but the lack of admixture from older planktonic assemblages into the poor but consistent planktonic sequence then would remain unexplained.

CRETACEOUS/TERTIARY BOUNDARY

The Cretaceous/Tertiary boundary, in the sense of a Maastrichtian/Danian contact, was cored twice, once at Site 216 where it is a disconformity within Core 23, Section 2, and then at Site 217 where the sum of the foraminiferal evidence seems to indicate that it falls between Core 16, CC and Core 17, Section 1.

At Site 216 (Table 4), Zone P.2 probably is present in Core 23, Section 1 but was not sampled. The two higher samples in Core 23, Section 2 both contain *Subbotina inconstans* and *Planorotalites compressa* and, therefore, are high in Zone P.1 (Figure 2). Preservation of specimens in this chalk is not good but is adequate for these identifications. Rare specimens of *Globotruncana* and *Rugoglobigerina* were found in the sample at 99-100 cm. The two lower samples in Core 23, Section 2 contain *Globotruncana*, *Rugoglobigerina*, and Heterohelicidae. The assemblages appear to lack typical Danian elements, but they are not complete, and *Globotruncanella mayaroensis* (indicating latest Maastrichtian) and *Globotruncana stuarti*

appear lower in Core 23 as the diversity increases downhole. The Cretaceous/Tertiary boundary accordingly is placed biostratigraphically between 99-100 cm and 110-111 cm in Core 23, Section 2. At about 105 cm, there is a change in sediment structure. Above, the sediment is darker, more homogeneous and relatively featureless although well worked biologically. Below, the sediment is heterogeneous, being mottled, with well-defined burrows (small crustaceans?) and traces of glauconite. In general, the evidence suggests that the higher, darker sediment has been worked downward more than vice versa, the few Cretaceous specimens at 99-100 cm and lack of Danian specimens at 110-111 cm notwithstanding. The section preserves a disconformity representing a hiatus between the *Globotruncanella mayaroensis* Zone and Zone P.1d, that is, perhaps 2 to 3 m.y. (Figure 2).

The foraminiferal-biostratigraphic record at Site 217 is rather different (Table 5). Typically Danian forms (*Eoglobigerina*, *Chiloguembelina*) occur down to Core 16, CC, and typically Maastrichtian elements (*Globotruncana*, *Rugoglobigerina*) were found up into Core 16, Section 5. No lithological changes were noted in the critical interval. The successive disappearance downwards of *Subbotina inconstans*, *Planorotalites compressa*, and *Subbotina pseudobulloides* is consistent with known ranges (Figure 2), and Zones P.1d and P.1c are identified accordingly. The identification of Zone P.1b is more tentative, but specimens close to *Subbotina triloculinoides* were found at 148-150 cm in Core 16, Section 6. *Eoglobigerina eobulloides* as identified here appears to include *Globigerina danica* (Bang, 1971) (see Berggren, 1971). The most striking element in the foraminiferal residues from Core 16, Section 6 and Core 16, CC is an abundant and relatively large globigerinid form which agrees optically with the surface texture and perforation in scanning photomicrographs of *Hedbergella monmouthensis* (Olsson, 1970, Bang, 1971). A typically diverse, tropical Maastrichtian assemblage appears in Core 17, Section 1. Accordingly, a seemingly almost complete, if less than perfect, Danian biostratigraphic record also

includes some Maastrichtian elements and unusual concentrations of *Hedbergella*. The Cretaceous/Tertiary boundary is placed below Core 16, CC on the tenuous evidence that this sample represents upward reworking rather than downhole contamination.

It seems unlikely that the foraminiferal distributions at Site 217 represent a true overlap of Cretaceous taxa and Tertiary taxa, as Bukry et al. (1971) suggest may well be the case in some sections. However, the "upward reworking" and concentration of *Hedbergella* are not explained clearly. It is noteworthy that the interpreted hiatus in the rather shallower section at Site 216 closely approximates, in terms of biostratigraphic interval, the extent of *Globotruncana/Rugoglobigerina/Hedbergella* overlap with *Eoglobigerina/Subbotina/Chiloguembelina* at Site 217.

UPPER CRETACEOUS

The *Globotruncanella mayaroensis* Zone was identified at Sites 216 and 217 (Tables 4, 5), but no other standard Cretaceous zone was recognized, and the Cretaceous assemblages at Sites 211 and 212 have not been correlated accurately.

The lowest sediment at Site 211, occurring between diabase and basalt, yielded a fairly diverse assemblage of small benthonic specimens but no planktonics. Genera include the agglutinated *Spiroplectammina*, *Goesella*, *Marssonella*, *Gaudryina*, *Glomospira*, and *Bathysiphon*, and the calcareous *Prebulimina*, *Reussella*, *Nuttallides*, *Pullenia*, *Gyroidinoides*, *Anomalinoides*, *Cibicides*, and *Angulogavelinella*. The assemblage is definitely of Upper Senonian to Maastrichtian aspect (*Angulogavelinella praecaucasica*, *Alabamina dorsoplana*), but no more precise correlation is made. The forms present are similar both taxonomically and preservationally to assemblages known to have accumulated in deep water (for example, high in the Maastrichtian at Site 217) although most of them are known also to have had close or conspecific counterparts on the shelf. Therefore, the absence of planktonics may indicate a depth great enough for planktonics to have been removed by selective solution. An alternative—inshore with restricted oceanic influence—seems less likely in the circumstances. Variation in the presence and amount of *Inoceramus* prisms is noteworthy.

At Site 212, the lowest carbonate unit (lower part of Cores 29 to 35) contains abundant planktonics and some calcareous benthonics, uniformly minute in size. The planktonic component is a *Globigerinelloides*-*Hedbergella*-*Heterohelix* assemblage with no juvenile *Globotruncana*. The assemblage undoubtedly has been size-fractionated. Specimens of cf. *Globotruncanella citae* indicate a Campanian-Maastrichtian age. In Core 36, an assortment of noncalcareous forms (*Pelosina*, *Ammodiscus*, *Glomospira*, *Bathysiphon*, *Reophax*, *Haplophragmoides*, cf. *Adercotryma*) is of deep-water origin. The lowest material at this site consists of a specimen in a thin section (Sample 39-1, 143 cm) of a calcareous-perforate foraminifer, quite possibly a buliminid and perhaps more of Cretaceous than Jurassic aspect.

Site 217 is almost eight degrees north of Site 216 (Figure 1), and differences between the respective

planktonic assemblages in the higher part of the *Globotruncanella mayaroensis* Zone seem ascribable to biogeographic distributions rather than preservation or other obscuring factors. Thus, those samples from Site 217 which have not had parts of the assemblage removed by solution seem to have the full complement of "tropical" forms: diverse double-keeled *Globotruncana* (*G. stuarti* s.s., *G. stuarti* s.l., *G. conica*, *G. elevata*); diverse double-keeled *Globotruncana* (*G. arca*, *G. aegyptiaca/duwi*, *G. contusa*); *Globotruncanella mayaroensis*, *G. intermedia*, and *G. citae*; *Rugoglobigerina* including occasional specimens approaching *scotti*; large, variable heterohelicids in all expected forms including *Gublerina cuvillieri*, *Pseudotextularia elegans/deformis* and *varians*, etc., *Pseudoguembelina* and *Planoglobulina*, etc. In the narrow interval at Site 216 (lower Core 23) between the shallow-water facies and the Cretaceous/Tertiary boundary, on the other hand, *Globotruncanella mayaroensis* is unusually common; the double keeled *G. arca* and *G. contusa* are relatively common but *G. aegyptiaca* was not observed; the *G. stuarti* group is present but developed poorly; large heterohelicids flourish much less; and the overall size of specimens is less. At this level at Site 216, corrosion and fragmentation occur but less so than at Site 217.

The lowest sample at Site 216 with *Globotruncanella mayaroensis* was Core 24, CC, thus being late Maastrichtian. Associated benthonics include *Stensioina*, *Angulogavelinella*, and *Cibicides*, and the assemblage, though poor, is of shelf facies. The contrast between Cores 23 and 24 indicates rapid sinking of the Ninetyeast Ridge at this site during the late Maastrichtian. The thick section from Core 25 to Core 35 is characterized by consistently low numbers of planktonic specimens (*Globotruncanella citae* down to Core 26, *Globotruncana arca* down to Core 25, otherwise only *Heterohelix*, *Guembelitra*, and ?*Hedbergella*) and sparse benthonics which, however, are rather diverse in terms of total taxonomic accumulation. Species present include members of *Gaudryina*, *Marssonella*, *Spiroplectammina*, *Lenticulina*, *Nodosaria*, *Marginulina*, polymorphinids, *Gyroidinoides*, *Angulogavelinella*, *Cibicides*, *Praebulimina*, and *Allomorphina*. Ostracods, echinoidal remains, the molluscan fragments, including *Inoceramus*, are present. No date beyond a generalized Campanian-Maastrichtian age could be given for the section below the base of *Globotruncanella mayaroensis*. The environment undoubtedly was shallow marine, as indicated by the low numbers of planktonics, and also, the selective nature of the assemblage (e.g., the consistent absence of *Globotruncana*) indicates somewhat restricted influence from the open ocean.

A threefold division on biostratigraphic and biofacies characteristics of the foraminifera-bearing Upper Cretaceous at Site 217 is summarized broadly in Table 7.

The highest unit at Site 217 has a diverse planktonic fauna, progressively affected upwards by corrosion and fragmentation of the tests. Thus, the interval in Cores 18, CC to 17, CC has a very poor assemblage although it improves markedly toward the top of Core 17, where the rich assemblage listed above was found. From Core 19 down to Core 23 there is a reduction in the overall diversity of the assemblage. The change includes disappearance of

TABLE 7
Facies Changes in Late Cretaceous, Site 217

Interval	Age	Characteristics (Mostly Foraminiferal)	Interpretation
Core 17 to Core 22	Late Maastrichtian Late Maastrichtian (<i>Globotruncanella mayaroensis</i> Zone above Core 24)	Planktonic assemblages becoming more diverse upwards (<i>Globotruncanella</i> , single-keeled and double-keeled <i>Globotruncana</i> , large heterohelicids, <i>Rugoglobigerina</i> . Planktonic numbers vary with preservation; preservation deteriorating upwards with corrosion and fragmentation; specimens stained brown. Benthonics consist of robust calcareous and agglutinated forms; prominent when planktonics mostly removed from solution (Core 17, CC to Core 18). (No <i>Inoceramus</i>)	Oceanic deepening to below lysocline Assemblages becoming "fully tropical" at top.
Core 23 to Core 30	Maastrichtian	Planktonics abundant, dominated by <i>Rugoglobigerina rugosa</i> s. l., double-keeled <i>Globotruncana</i> especially <i>arca</i> , <i>Gublerina</i> , <i>Heterohelix</i> and <i>Globigerinelloides</i> ; diversity lower than above, <i>Pseudotextularia</i> rare, single-keeled <i>Globotruncana</i> virtually absent. Planktonic numbers increasing upwards, more abundant than in lower or upper units; preservation deteriorates upward as corrosion becomes more apparent. Benthonics decreasing upward. (<i>Inoceramus</i> abundant lower, decreasing upward; oysters present.)	Oceanic to Outer Shelf Assemblages "extratropical"
Core 31 to Core 36	Campanian	Planktonics common to abundant above Core 36; mostly an association of <i>Archaeoglobigerina</i> , <i>Globotruncana linneiana</i> s.l., <i>Globigerinelloides</i> and <i>Heterohelix</i> with <i>Globotruncana arca</i> becoming prominent near top. Preservation moderate to good; no corrosion by solution. Benthonics more common than in higher units, mixed calcareous-lamellar and agglutinated assemblages (<i>Goesella</i> , <i>Gaudryina</i> , <i>Angulogavelinella</i> , <i>Karrerina</i> , <i>Gyroidinoides</i> , <i>Valvalabamina</i> , <i>Allomorphina</i> , <i>Praebulimina</i> , <i>Nuttallinella</i> , <i>Ellipsoidella</i> , lenticulinids, nodosariids); miliolids rare. (<i>Inoceramus</i> present; also echinoid remains, sponge spicules, ostracods.)	(? deepening to outer shelf) Inner Shelf Assemblages "extratropical"
Core 37		Foraminifera not found.	

the *Globotruncana aegyptiaca/duwi* group, reduction in numbers and morphotypic variation of the group of single-keeled *Globotruncana*, and reduction in morphotypic variation in heterohelicids related to *Pseudotextularia*. *Globotruncanella mayaroensis* is recorded down to Core 23, CC and *G. intermedia* continues into Core 24, Section 1 to 24, CC. The change with time in the development of planktonic assemblages from Core 24 upwards is particularly striking because, in the development of the rich late Maastrichtian microfaunas, *Globotruncanella mayaroensis* is the last major element to appear, whereas, at Site 217 it is the first. The differences between the top and base of this unit match rather well the differences between the top of the unit and the deep-water assemblage at Site 216.

The section from Core 23 to Core 30 is distinguished as the middle unit in Table 7. In this section the appearance of *Inoceramus* prisms in residues (Core 23) and an increase in abundance of *Rugoglobigerina rugosa* s.l. mark a change to shallower-water conditions. The planktonic assemblages contain abundant specimens, but they almost all fall into a few, if variable, groups: *Rugoglobigerina rugosa* s.l., double-keeled *Globotruncana* of the *G. lapparenti-linneiana-arca* spectrum (*arca* dominant), *Heterohelix globulosa*, *Gublerina*, and *Globigerinelloides*; *Globotruncana fornicata* and *Pseudotextularia* are rare and single-keeled *Globotruncana* is virtually absent. Benthonics include *Osangularia*, *Gyroidinoides*, *Valvalabamina*, *Cibicides voltziana*, etc., *Bolivina incrassata gigantea*, and rare *Bolivinoidea* (*B. miliaris* in Core 27). Preservation deteriorates upwards as corrosion and fragmentation

increase. The age of this unit is late Maastrichtian at the top, mid Maastrichtian in Core 24 (*Globotruncanella intermedia*) and may be entirely Maastrichtian; however, the spectacular disappearance of planktonic species means that biostratigraphic resolution also disappears.

In the third unit (Table 7), where there is a decrease in the abundance of *Inoceramus* prisms and silica appears in the sediment, the planktonic assemblage changes. *Globotruncana arca* is prominent down to Core 31. Lower assemblages are dominated by *Archaeoglobigerina cretacea*, *A. blowi*, *Globotruncana linneiana*, and related morphotypes, *Heterohelix*, and *Globigerinelloides*. *Globotruncana* aff. *fornicata* and *G. aff. rosetta* are present. The unit is of Campanian age. Foraminifera were found down to Core 36 at Hole 217 and down to Core 14 at Hole 217A. Planktonics are present but rare in comparison with benthonics in the basal part of the unit. Benthonics in the unit as a whole include *Karrerina ribbingae/excavata*, *Angulogavelinella rakauoana*, *Nuttallinella coronula*, and the genera listed in Table 7.

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